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(54) Quench detector for superconducting winding

(57) To detect transitions from the superconducting to the normal state in a superconducting winding, a detector wire of similar superconducting material to the main winding but of smaller dimensions and therefore higher normal resistance is provided. It extends along the main conductor in close thermal relation to respond to changes of temperature in the main conductor. To minimize the effect of magnetic field fluctuations the detector is arranged as a bi-filar pair which may be within the outer sheath of an internally-cooled main conductor or wound helically around it. The detector wire resistance is monitored at a fraction of the critical current, conveniently with direct current and a voltage responsive detector.

GB 2 126 028 A

SPECIFICATION
Quench detector for a superconducting winding

The present invention relates to a quench detector for a superconducting winding. Quench detectors serve to detect transitions from the superconducting to the normal, resistive, state in any part of the winding so that the current can be reduced to zero before overheating of the winding can occur.

For static superconducting windings there are several known types of quench detector which respond either to the electrical changes in the winding or to the resulting temperature rise. For a rotating or static winding which is subject to time-varying fields the conventional electrical detectors tend to give spurious quench indications as a result of the influence of transient field changes. The difficulty of measuring the small voltages involved is increased when the rotation of the winding is involved. Additionally a rotating superconducting winding which is subject to time-varying fields is normally cooled by helium flowing through or around the conductor and the large specific heat of the helium slows down the rate of growth (propagation velocity) of a normal region and thus requires greater sensitivity in the quench detector if it is to respond within a reasonable time.

In accordance with the present invention there is provided a quench detector for a superconducting winding, the quench detector comprising a superconducting detector wire extending throughout the length of the conductor forming the superconducting winding, means for supplying current to the detector wire and means for detecting electrical changes in the detector wire resulting from changes of temperature in the main superconducting winding.

Thus the invention departs from using measurements based on the main winding and depends on a detector wire which follows the course of the main winding and whose temperature at every point is controlled by the condition of the main winding at that point. For manufacturing reasons it is necessary to co-process the superconducting detector wire with a normal (i.e. nonsuperconducting) material such as Cu-Ni or copper. The normal component can nevertheless be chosen to have an appropriately high resistance.

The main winding may be composed of an internally cooled cabled superconductor, that is to say a conductor consisting of a bundle of superconducting strands surrounded by liquid helium which is enclosed in a metal sheath. The detector wire may then run within the outer sheath of the main conductor. The detector wire may have its own sheath to separate it from the strands of the main conductor and support the small diameter superconducting wire.

The detector wire may advantageously be of non-inductive construction to minimise inductive effects resulting from the time-varying external fields. For similar reasons the strands of the main winding are transposed and the detector wire itself may be transposed with the strands of the main winding.

In an alternative arrangement the detector wire is wound around the outside of the main conductor. The winding is preferably helical with a pitch which is several times the diameter of the main conductor and in order to minimize inductive effects the detector wire is arranged as a bi-filar helix consisting of a pair of wires joined at one end and following the same helical path. The detector circuit can thus be connected to the free ends of the detector wire at one end of the main conductor. A layer of electrical insulation is provided between the main conductor and the detector wire but this is chosen so that it does not prevent the detector wire responding to the change of temperature of the main conductor.

Under operation conditions the temperature of the detector wire is governed by that of the main winding. However when a change in any part of the main winding triggers a corresponding change in the detector, the quench in the detector wire propagates much more rapidly than that in the main winding because of the small dimensions, the lack of a relatively low resistance stabilizing material and consequently higher resistivity of the detector wire with the result that the detector wire increases in temperature over a long length (such as tens of metres) and a large change in the resistance of the detector wire occurs within a short time.

For simplicity the power supply to the detector wire is direct current or low frequency alternating current. The detection means may measure the voltage along the detector wire or the current passed.

A superconducting main winding which is cooled by liquid helium can accommodate transient energy inputs which drive it into the normal conductive state and from which it can recover within a period of a few milliseconds. It is only if the energy input persists that a quench condition will be set up and grow in such a way as to be dangerous. Thus the detector wire should preferably not respond to transient temperature changes in the main winding on a millisecond timescale. This is partially achieved by making the detector responsive to the temperature of the helium coolant. Additionally the response may be delayed by, say, 15 to 30 milliseconds by the provision of a thermally insulating sheath around the detector wires. Such a sheath must nevertheless allow removal of heat generated within the detector wire by field variations which are within the tolerance of the main winding.

The invention is applicable, for example, to an alternating current generator of the type described in U.K. Patent Specification No. 1,315,302, which is suitable for generating energy for the grid system and has a superconducting winding supported on a rotor and forming the field winding of the machine. Such a winding possesses a large stored energy,

of the order of several MJ, and the consequence of a quench in such a winding could be catastrophic if it is not promptly detected so that the current in winding can be rapidly reduced. It is also applicable to any large superconducting magnet which requires a highly sensitive quench detector.

The winding typically consists of strands each of which is a composite of copper with niobium/titanium superconductive material. The strands are formed into a transposed or plaited bundle which is surrounded by liquid helium contained within a metallic sheath. This is known as an internally cooled cabled superconductor. In one arrangement the detector consists of a twisted pair of noibium/titanium wires each 0.2 mm in diameter which are surrounded by a sheath of PTFE and an outer metal sheath with an overall diameter of 1 mm. The wires of the detector are joined together at one end to form a bi-filar pair and their other ends are connected by way of copper leads to a power source at ambient temperature. The detector runs along the full length of the conductor forming the superconducting winding and is disposed within the sheath of the main conductor to respond directly to the temperature of the helium in the main conductor.

In an alternative arrangement the detector wire is of rectangular cross-section and consists of strands of Nb-Ti superconductor in a Cu-Ni metric. The wire is again connected as a bi-filar pair which is wound helically around the outside of the main conductor, which may again be an internally-cooled cabled superconductor. A layer of electrical insulation, for example a fabric impregnated with synthetic resin, is applied to the outer surface of the main conductor before the detector wire is wound on. For a main conductor of 10 mm diameter the detector wire may be 2 mm×0.15 mm in cross-section for each part of the bi-filar pair and wound helically at a pitch of 100 mm. The layer of electrical insulation may be of 0.15 mm thickness.

It will be noted that in each case the cross-sectional area of the detector wire is no more than a hundredth of that of the main conductor and a similar relationship exists between the cross-sections of the superconducting elements of the main conductor and the detector wire. Hence the normal resistance of the detector wire is very much higher than that of the main conductor and a quench in the detector wire, that is a change to normal conductivity because of increased temperature results in a more easily detectable voltage change.

The power source of the detector is preferably direct current or may be low frequency alternating current. The power may be supplied to the detector and the electrical condition of the detector may be monitored by a variety of methods including conventional sliprings, a rotating pick-up coil on the rotor supplied and monitored by a static excitation coil and, for monitoring, radio telemetry. For convenience and simplicity direct current is supplied by sliprings and the voltage across the detector is monitored.

The detector wire is preferably operated at a fraction of the critical current in order to ensure that the detector will quench only when heated and not in response to fluctuations in the magnetic field. This may be as low as 1% or 2% or as high as 50% but is conveniently around 25% of the critical current.

If the temperature of part of the main conductor rises to a level such that it ceases to be superconductive and returns to a normal resistivity there is, of course, a change in voltage across the main winding. The region of normal resistivity may be transient but if it extends over a length of 50 mm of the main conductor it is then likely to grow and propagate if the current is not reduced. The main conductor has a normal resistance of the order of 10^{-5} ohms/m and hence the voltage arising is of the order of 5 mV. However over a similar length of the detector, with a normal resistance of the order of 20 ohms/m the voltage occurring is about 25 V. It is evident that this change of voltage is very much more easily monitored. The response time of the detector is arranged to be between 5 m sec and 200 m sec to allow transient changes which last less than 5 m sec to go undetected while giving a more rapid response to longer lasting faults than could be obtained from the winding itself.

An advantage in using the same superconductor material (Nb-Ti) for the detector and for the rotor conductor is that their response to a certain temperature variation is similar at all points in the winding. In low field regions a temperature rise from typically 4 K to 7 K may be needed to quench the rotor conductor with the quench detector being triggered at a further 1 K rise. At high field regions, the temperature to cause a quench in the rotor conductor could be 5 K (not 7 K) and the quench detector would again be triggered at a further 1 K rise. The time taken for the conductor temperature to rise 1° is of the order of 30 m sec to which can be added the, say, 20 m sec response time of the detector, giving an overall response time of much less than 100 m sec. This compares well with the usual 200 m sec response time of a conventional static superconducting coil without external fields.

To increase the voltage and thus the sensitivity additional pairs of detector wires may be included.

The detector wires may additionally be used for determining the maximum temperature at any point in the winding before the winding is energised. This can be done by raising the current in the detector wires to the quenching point of the detector. The low stored energy of the detector allows this to be done safely. It may be necessary for this purpose to have the detector wires composed of a superconducting material different from that of the main winding.

Claims

1. A quench detector for a superconducting

winding, the quench detector comprising a superconducting detector wire extending throughout the length of the conductor forming the superconducting winding, means for supplying current to the detector wire and means for detecting electrical changes in the detector wire resulting from changes of temperature in the main superconducting winding.

2. A quench detector as claimed in claim 1 in which the detector wire is constructed as a bi-filar pair.

3. A quench detector as claimed in claim 1 or 2 in which the detector wire is wound helically about the outside of the winding conductor.

4. A quench detector as claimed in any of claims 1 to 3 in which the detector wire is composed of superconducting filaments in a non-superconducting matrix.

5. A quench detector as claimed in any of the preceding claims in which the cross-sectional area of the detector wire is less than one hundredth of that of the main conductor.

6. A quench detector as claimed in any of the preceding claims in which the current supply means is a direct current supply means.

7. A quench detector as claimed in any of the preceding claims in which the detecting means is responsive to changes in voltage across the detector wire.

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